

PTO/PCT Rec'd 11 MAY 2001

SCANNING OF ELECTROMAGNETIC BEAMS

09/831555

This invention relates to a device which is adapted to be positioned in the path of a beam of electromagnetic radiation to control its direction. The invention is particularly, but not exclusively, concerned with devices for directing microwave radiation.

The term microwave is generally understood to refer to the part of the electromagnetic spectrum between infra-red radiation and radiowaves. Typically this is stated to be substantially in the frequency range 1 to 300GHz, although sometimes it is stated to be in the frequency range 0.2 to 300GHz . It includes that part of the spectrum referred to as millimetre wave which is stated to have a frequency in the range 30 to 300GHz.

Communication systems have been proposed in which one or more communication channels are transmitted in a particular direction in the form of a modulated electromagnetic beam propagating through free space, for example the atmosphere. An advantage of such a directional communication system over a communication system which broadcasts omnidirectionally is that there is a greater degree of security in that the communication channel or channels can be directed towards a particular location. For example, if omnidirectional transmission is used, not only can others receive the transmission readily but the presence, and possibly the location, of the transmitting station can be determined.

In one embodiment, units which are spatially separated need to communicate with each other. If any of the units are mobile, then the directional communication channel could

come from any direction in an azimuthal plane. It then becomes important to establish the direction from which a communication channel is coming in order that a reply can be sent in the correct direction. Although this can be done by having a number of antennas pointing in different directions, a single omnidirectional antenna is preferred.

In a known device for electronically steering a microwave beam comprises a body of ferrite material having an aperture through which the beam passes. Located on opposing sides of the aperture are magnetic coils which apply a magnetic field across the body which induces a gradient in magnetisation across the body. The resultant direction of the beam leaving the device is generally perpendicular to the gradient in the magnetic field across the body. Therefore the amount by which the beam is steered is controlled by the gradient in magnetisation. Across its width, the beam passes through the same thickness of ferrite material. Such a device is described in GB 9722720.1. If the device is provided with magnetic coils on two opposing sides of the aperture, the device can steer the beam in a single plane. If the device is provided with a plurality of magnetic coils, typically four, each being located adjacent a side of the aperture, the device can steer the beam in two or more planes, that is, conical steering. Variation of current supplied to each pair of coils provides steering of the beam to some extent, for example  $\pm 25^\circ$ .

In certain applications it is desirable to scan a microwave beam through  $360^\circ$  in an azimuthal plane. In this context an azimuthal plane is perpendicular to the original direction of the beam before it was steered. To achieve  $360^\circ$  azimuthal steering a mechanical beam steering or scanning device is used. Such a device typically has a reflective surface inclined to an axis, typically by  $45^\circ$ , which is rotated about that axis.

A disadvantage of such mechanical scanning is that moving mechanical components have momentum and take a finite, and potentially excessive, time to stop.

US-A-4 740 791 discloses a microwave antenna which comprises an array for transmitting radiation received from a source towards a first reflector in the form of an elliptic or parabolic skull cap. The first reflector reflects the received radiation towards a second reflector in the form of a concave ring at whose centre is positioned the array. The second reflector has a concavity towards the first reflector. Radiation can leave the antenna in any direction in accordance with radiating elements of the array.

In accordance with one aspect of the invention there is provided a device for controlling the direction of a radiation beam, the device comprising:-

transmission means for transmitting the radiation beam from a radiation source;  
and

steering means for steering the radiation beam;

characterised in that the transmission means comprises a body of magnetic material having a central axis which forms an aperture through which the radiation beam passes, the central axis being parallel to and coincident with the direction of the radiation beam prior to incidence on the transmission means;

and in that the steering means causes the radiation beam to emerge from the transmission means offset relative to the central axis in free space in a known direction.

When the steering means is varied the beam follows a steered direction so that on emerging from the aperture the beam may be offset relative to the axis and steered about the axis so as to define an angle  $\theta$  between the axis and the steered direction and the beam is then reflected so that the emergent direction of the beam from the device relative to the axis is greater than angle  $\theta$ .

In one embodiment of the invention, the steering means is magnetic means. Preferably the magnetic means applies a gradient in magnetisation across the aperture. Preferably this

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gradient in magnetisation occupies a plane which is not perpendicular to the axis. Although the term plane is used, this describes the gradient of magnetisation in an ideal case. The gradient might be non-planar due to non-ideal conditions in its generation. Preferably the gradient of magnetisation rotates about the axis.

An advantage of electronic beam scanning is that no moving parts are involved and halting a scan or switching the beam between particular directions can be almost instantaneous.

Preferably the axis passes through the centre of the aperture. However, it may not necessarily do so but may be a nominal axis chosen according to the propagation direction of the beam.

The offset between the beam and the axis may be angular. Preferably it is spatial. If there is a spatial offset the angle  $\theta$  may be small. It may be zero.

In another embodiment, the steering means may comprise a ferrite material arranged within a solenoid so as to rotate a linearly polarised beam about the axis. A pair of polarisers may be arranged adjacent either end face of the ferrite material so as to reflect or to allow the beam to pass. Preferably, an isolator may be arranged to prevent a reflected portion of the beam reflected from the polarisers from entering a horn used to generate the beam. An absorbing material may be arranged to absorb that portion of the beam which is reflected.

Conveniently the beam is reflected by a reflective surface placed adjacent to the face of the aperture or array from which the beam emerges. This face is an emergent face. Preferably the reflective surface is in the shape of a cone having its apex facing the emergent face and its central axis coincident with the axis of the device. It will be understood that the cone may be a section of a cone.

Preferably the device sweeps the beam through 360° of a plane which is perpendicular to the axis.

Preferably the beam of radiation is microwave radiation. Most preferably it is millimetric radiation. In one embodiment it is a Ka band, typically between 26.5 to 40GHz, and in another it is at W-band, typically between 75 to 110GHz. Alternatively the radiation is in other parts of the electromagnetic spectrum, for example at high frequencies towards, and including, optical and visible frequencies.

In accordance with another aspect of the present invention, there is provided a communications unit incorporating a device as described above, and which includes radiation receiving means, modulation and demodulation means for modulating and demodulating information onto and from the radiation beam.

In accordance with a further aspect of the present invention, there is provided a communications system comprising a plurality of communications units as described above.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 illustrates a unit to deflect a beam of radiation;

Figure 2 illustrates a perspective view of the unit of Figure 1;

Figure 3 illustrates the unit of Figures 1 and 2 in plan view;

Figure 4 illustrates the unit of Figures 1 and 2 incorporated into a beam scanning device;

Figure 5 illustrates alternative embodiment of the invention;

Figure 6 illustrates the construction of a ferrite device;

Figure 7 illustrates an alternative construction of a ferrite device;

Figure 8 illustrates a cross sectional view of the ferrite device in Figure 7 and the flux lines generated by coils;

Figures 9a and 9b illustrate sectors into which a ferrite device can be divided in order to provide a directional response;

Figure 10a and 10b illustrate embedded coils for providing a directional response for the ferrite device shown in Figures 5 to 8; and

Figures 11 to 13 illustrate various alternative embodiments to that shown in Figure 5.

Figure 1 shows a unit 10 which is used to deflect a beam of radiation 12 transmitted from a microwave horn, as best illustrated in Figure 4. The unit 10 comprises a body 14 of ferrite material having a quarter wave plate 16 located adjacent an entry face 18 of the body 14 and a phase correcting dielectric 20 located adjacent an exit face 22 of the body 14.

Although reference is made to a beam 12, implying that there is a spot of energy, it is to be understood, of course, that the radiation is in the form of an energy distribution.

The body 14 provides a magnetisable medium through which the beam 12 passes. In effect therefore, it comprises an aperture. Opposite faces of the body 14, that is opposite sides of the aperture, are provided with anti-reflective coatings. The body 14 has a central axis 24 which passes through the centre of the aperture, parallel to the beam of

radiation 12. Pairs of biasing coils 26 and 28 and 30 and 32 are located about sides 34, 36, 38 and 40 of the body 14, as best illustrated in Figure 3. The coils are wound about parallel axes which are themselves parallel to the central axis 24. As a consequence of their orientation, when an electric charge is carried by the coils 26, 28, 30 and 32 they are energised and apply a magnetic field to the body 14 in a direction generally perpendicular to a mid-plane of the body 14 located parallel to, and equidistant from, the entry and exit faces 18 and 22. The magnetic field aligns internal magnetisation in the body 14 to enhance net magnetisation in a direction parallel to the magnetic field.

The effect of the magnetic field on the ferrite material of the body 14 and the interaction between magnetised ferrite material and a microwave beam 12 is described in GB 9722720.1. A microwave beam 12 passing through the magnetised material will interact with it and this interaction changes velocity of parts of the beam 12 across its width. A uniform magnetisation, that is having a zero gradient, present across the body 14 will uniformly change the velocity of the beam 12 across its width. However, if a non-zero gradient in magnetisation is present across the body 14 this causes a differential phase shift in the beam 12 across its width. If the beam 12 is circularly polarised it emerges at an angle deviated from its original direction on entering the body 14. If the beam 12 is linearly polarised, which is effectively a combination of two circularly polarised beams of opposite senses, two circularly polarised beams emerge at equal and opposite angular deviations.

The unit 10 is also shown in Figure 2 in perspective view, where the configuration of the coils 26, 28, 30 and 32 can be more clearly seen wound respectively about arms 42, 44,

46 and 48 which extend from the sides of the body 14. Since the coils 26, 28, 30 and 32 produce the desired gradient in magnetisation when current in the same direction is applied, the coils of each pair can conveniently be wound from a continuous piece of wire. If the coils are wound in the same direction, the direction of the current in each needs to be in opposite directions. In this embodiment it can be seen that coils 26, 28, 30 and 32 in a particular pair are wound in opposite directions. As a result, if the coils 26, 28, 30 and 32 in a particular pair are driven with current in the same direction, magnetic fields having opposite directions are generated by each coil 26, 28, 30 and 32. In this way a non-zero gradient in magnetisation results.

The arms 42, 44, 46 and 48 can either be integral with the body 14 comprising the same material or can be separate pieces of the same or of a different material. If separate pieces are provided it is necessary to ensure that a good magnetic circuit between the arms 42, 44, 46 and 48 and the body 14 is provided so as to provide a medium through which the magnetic field can pass into the body 14.

The magnetic field produced by one of the coils, for example 26 or 30, is in an opposite direction to that produced by the other of its pair, for example 28 or 32. In this way each pair of coils 26, 28, 30 and 32 induces a gradient in magnetisation across the body 14, from one side to the opposite side. If both of the pairs of coils 26, 28, 30 and 32 are inducing a gradient in magnetisation, a composite gradient in magnetisation results.

If the coils 26, 28, 30 and 32 in a particular pair are each energised with periodically oscillating electrical signals and the oscillating signals applied to each pair are in



quadrature, that is  $90^\circ$  out of phase, this will cause the composite gradient in magnetisation to rotate about the central axis 24. If the coils 26, 28, 30 and 32 are identical and applied currents are similar, having opposite directions where appropriate, this will cause the beam 12 to emerge from the exit face 22 at locations about a circular path centred on the central axis 24. A schematic representation of such a circular path 50 described by the beam 12 on the exit face 22 is shown in Figure 3. Of course, the path 50 does not have to be circular but may be any shape suitable for operation of the unit 10. Generally, the shape of the path is governed by the phase relationship of the oscillating signals applied to the pairs of the coils 26, 28, 30 and 32. Therefore, in certain circumstances, the phase relationship will be other than in quadrature.

Figure 4 shows the unit 10 incorporated into a beam scanning device 60. The same references have been used to label similar integers to those illustrated in Figure 1. The unit 10 is located between a microwave horn 62 and a cone shaped reflector 64. Since the reflector 64 is arranged so that its apex faces the exit face 22 and its central axis is coincidental with the central axis 24, it will be appreciated that as the beam 12 emerges from locations about the circular path 50, it will be reflected from a part of the reflective surface of the reflector 64 located as a circular path about the central axis 24. A potential problem with a cone reflector is that it naturally causes the beam to diverge significantly. One way to reduce this is to increase the size of elements in the device 60, such as the reflector 64, relative to the size of the beam 12 footprint. Finite limits exist as to reasonable sizes for such elements, given particular applications. Alternatively the reflector 64 can be modified to have particular focussing properties. For example if the reflector 64 does not have a constant taper angle but has a taper angle which increases as

the apex is approached, so that in elevational view it appears to have concave sides, then the beam 12 can be focussed in a particular plane, ideally an azimuthal plane which is perpendicular to the central axis 24. Naturally this does not provide focussing in a plane occupied by the central axis 24. Therefore the reflector 64 may be replaced by a composite set of reflectors each having suitable focussing properties in both planes. Although such an arrangement would have optimised reflection only in certain fixed directions, this may be suitable for particular applications. In one embodiment a reflector in the shape of a cone having a reflective surface machined or constructed so as to optimise the reflective regions so that 360° scanning is possible with optimised reflection occurring in certain fixed directions.

A further refinement of the reflector 64 is to provide it with a non-reflecting end. If the relative sizes of the footprint of the beam 12 and the offset from the central axis 24 are such that the footprint overlaps the central axis 24 then the device will transmit radiation in all azimuthal directions. If the axis of the beam 12 and the central axis 24 coincide, the radiation will be transmitted isotropically in azimuth. If there is a slight offset, although radiation will be transmitted in all directions, the radiation will have maximum and minimum values located 180° apart in the azimuthal plane. A non-reflecting end can ensure that the beam 12 is reflected from a single side of the central axis 24 only and thus results in transmission of a single beam 12. A non-reflecting end can be provided by coating the apex and surrounding region with a microwave radiation absorbing material or truncating the end and providing either radiation absorbing means or providing means to reflect radiation in non-critical directions from the reflector 64. Assuming that the reflector 64 has a correctly chosen cone angle, the beam 12 will be scanned 360° through

a plane which is perpendicular to the central axis 24.

Additional components are provided to optimise operation of the device 60. The quarter wave plate 16 located adjacent the entry face 18 is provided to convert linearly polarised radiation transmitted by the horn 62 into circularly polarised radiation. However, if a horn 62 is used which transmits circularly polarised radiation, the quarter wave plate 16 will not be necessary. It is preferred to use a beam 12 of circularly polarised radiation because it is deviated as a single beam 12 as is discussed above. However, if a beam 12 of linearly polarised radiation is used, which is consequently split into two circularly polarised beams, they would be reflected by the reflector 64 at an angular separations of  $180^\circ$ , thus doubling the scanning rate of the device.

The phase correcting dielectric 20 is provided to optimise the direction taken by the beam 12 as it emerges from the exit face 22 of the body 14 and is reflected off the reflector 64. As can be seen in Figures 1 and 4 the passage of the beam 12 through the body 14 is schematically illustrated as a curved path 66. As a result the beam 12 will tend to emerge from the body 14 in a direction not parallel to the central axis 24. The phase correcting dielectric 20 changes the direction of the beam 12 so that it travels towards the reflector 64 in a direction parallel to the central axis 24. Such a direction is preferred so as to minimise the size of the device 60 and reduce divergence in the reflected beam 12. The phase correcting dielectric 20 is in the form of a shallow cone having a large taper angle. The taper angle is chosen to provide azimuthal scanning. It will be understood that the phase correcting dielectric 20 is not essential to the invention as an arrangement is envisaged having a reflector 64 situated to reflect the beam 12 as it emerges from the

body 14 along its curved path 66.

Although the unit 10 and the beam scanning device 60 have been described transmitting radiation, in certain embodiments they are to be used to receive as well as to transmit.

For example, in a communication system, if a station receives a signal to which it is convenient or it is necessary to respond, such as an interrogation signal, it is desirable to determine the direction from which the signal originates. In this way a response signal can be transmitted in that direction only rather than omnidirectionally.

In a particular embodiment of a communication system a typical interrogation sequence might proceed as follows. The station to be interrogated is identified and an interrogating station transmits an interrogation signal. The interrogation signal typically has a first portion simply comprising a pulse of electromagnetic radiation which can be detected by the station being interrogated to know that an interrogation sequence has begun. It is not necessary for the pulse to contain any data and it may be about 100µs in duration. Following the first portion, a second portion containing data is transmitted, for example in a burst 300 to 400µs in duration. Therefore, the station being interrogated has 400 to 500µs to determine the direction from which the interrogation signal is originating in order that it can send its response signal in the correct direction.

If the device 60 is also being used as a transceiver, that is both to transmit and to receive radiation, it can scan to receive. In such a receive mode, at any single point in time the unit 10 is electrically biased by a small amount such that radiation is being preferentially received from one sector and less preferentially received from other sectors. The coils

26, 28, 30 and 32 of the unit 10 are electrically biased such that the composite gradient in magnetisation rotates about the central axis 24, thus scanning through 360° including both the preferential receiving and less preferential receiving sectors. When the electromagnetic pulse is received by the unit 10, irrespective of its angular orientation with respect to the preferential receiving sector, some of its power will be detected and processing means associated with the device 60 will determine that the station being interrogated is, indeed, being interrogated. Following this, as the receiving sectors are being scanned through 360°, the processing means can identify the electrical biasing at which maximum electromagnetic power is received and thus determine the direction from which the interrogation signal originates. Once the direction has been identified, in making its response the unit 10 of the responding station can be electrically biased so that there is a clear offset between the beam 12 and the central axis 24 to transmit the beam in a single azimuthal direction only, towards the interrogating station, rather than isotropically.

In another embodiment of the device 60, the unit 10 is omitted and replaced with a phase array. Controlling the relative amplitude and/or phases of elements of the array enables it to output a beam in chosen directions and therefore, by dynamically altering the relative amplitudes and/or phases of the elements, to steer the beam conically. Since the beam can therefore be used to describe in a nominal plane a circular path similar to path 50, then, if used together with a suitably located and suitably shaped, for example conical, reflector, it can also be used to scan the beam through an azimuthal plane. In such a modified system, it would be necessary to physically separate the array and the reflector to a sufficient extent so that the steered beam falls largely or wholly on one side of the

central axis of the reflector at any one time. By careful control of the relative amplitudes and/or phases, the beam could not only be steered but also focussed so that a relative narrow beam is produced on reflection by the reflector. It will be understood that if such a scanning transmitter is produced, the array could be configured so that it can receive radiation as well. In this case, the phase array could scan for received signals in a manner similar to that described above and, when such a signal and its direction has been determined, transmit a response in the desired direction.

Alternatively, the phase array could comprise a plurality of sub-arrays which are independently energised and arranged so that energy produced by each element of the sub-array corresponds to a specific direction in azimuth thereby providing directionality of the beam in azimuth.

Furthermore, the phase of the array or elements of the sub-array can be varied to compensate for divergence of the beam when reflected from a conical spaced reflector.

Generally, there are systems other than communication systems in which determining the direction of origin of radiation is desirable. Such systems may be tracking systems.

In another embodiment, as illustrated in Figure 5, a linearly polarised beam 70 is arranged to pass through a ferrite device 71, which has induced therein uniform longitudinal magnetisation arranged to alter the polarisation state of the beam 70. The plain polarisation of a linearly polarised beam 70 will rotate as it propagates through the longitudinally magnetised ferrite device 71. A ferrite device 71 can typically be

constructed by placing a ferrite material in a solenoid.

However, this provides a bulky arrangement which can not be easily integrated into a communication system. Accordingly, as illustrated in Figure 6, a coil 72 of a solenoid is buried within a suitable ferrite material 73 and when energised it will induce a substantially uniform longitudinal magnetised effect on the ferrite material 73. This offers a compact solution to provide a ferrite device 71 suitable for use in a communication system. In addition, the arrangement of Figure 6 minimizes the demagnetising effects since a magnetic field is generated within the ferrite material 73.

In Figure 7, the efficiency of the ferrite device 71 illustrated in Figure 6 can be improved by providing a pair of coils 72a and 72b which are accordingly spaced in a Helmholtzian coil arrangement so as to create a uniform longitudinal field and increase the magnetisation of the ferrite material 73 at the extremities of the ferrite device 71.

Furthermore, as illustrated in Figure 8 the addition of a soft iron sleeve 74 arranged around the periphery of the ferrite material 73 will improve the magnetic circuit and minimize the thickness required of the ferrite material 73 for adequate return path of flux lines generated by the coils 72a and 72b. Alternatively, if an air gap is created between the return path and the forward direction of the flux lines created by one of the coils 72a or 72b this will achieve an improved magnetic circuit and the other coil 72a or 72b will not be required for a substantially long ferrite device 71.

The ferrite devices 71 described in Figures 6, 7 or 8 can be incorporated into the arrangement illustrated in Figure 5. Figure 5 illustrates a quasi-optical type polarisation

switch or rotator wherein the ferrite device 71 is positioned between a pair of first and second polarisers, 75 and 76 respectively. The polarisers 75, 76 are typically formed from wire grids which are arranged to reflect or allow some or all of the beam 70 to pass according to each polarisers 75, 76 state.

A horn 77 is arranged to transmit the beam 70 along an axis 78 which passes through the ferrite device 71. The first polariser 75 is inclined to the axis 78 and is arranged to allow the beam 70 to pass therethrough and to remove any cross polarisation in the beam 70 generated by the horn 77. This is achieved by reflecting cross polarised radiation generated by the horn 77 onto a suitably arranged absorbing material 79.

The addition of a cone shape reflector 81 allows the beam 70 to be reflected into free space through  $360^\circ$  in a plane substantially perpendicular to axis 78, that is in this case the azimuth plane, and hence, in the right conditions to pass through the second polariser 76. In this embodiment it will be understood that the second polariser 76 is shaped to surround the reflector 81 and the beam 70 is allowed to pass, into free space, as a pair of beams 70a and 70b separated by  $180^\circ$  in a scanning type arrangement, when the beams 70a and 70b are correctly polarised, otherwise the beams 70a and 70b will not pass through the second polariser 76.

To best understand the operation of the apparatus in Figure 5, the apparatus should firstly be considered without the presences of the second polariser 76. The beam 70 will be reflected as a notional reflected beam from the cone shaped reflector 81 into free space through 360 degrees in a plane substantially perpendicular to the axis 78, that is in the



azimuth plane. The polarisation vector, in the far field of the reflected beam, will undergo a complete rotation when viewed over a  $2\pi$  azimuth plane.

The vertical direction of the polarisation vector of the reflected beam in the far field will coincide with the direction of the field in beam 70, in the azimuth plane. When the ferrite device 71 is in a unenergised state, that is coil 72 or coils 72a and 72b are not energised, the direction of the field in the beam 70 will be in the same direction as when it emerged from the horn 77.

The effect of introducing the second polariser 76, which surrounds the cone shaped reflector 81, is to allow energy to emerge only in certain directions. The direction of the emerging energy will be maximum in the direction in which the polarisation of the reflected beam from the cone shaped reflector 81 coincides with the transmission characteristic of the polariser 76.

If the polariser 76 is designed to transmit vertical polarisation then, when the ferrite device 71 is in an unenergised state, that is coil 72 or coils 72a and 72b are not energised so as to rotate the beam 70 about the axis 78, the beam 70 will pass through the ferrite device 71 and the azimuth direction of the reflected beam will coincide with the direction of the field in the beam 70, in the azimuth plane, which is in the same direction as when it emerged from the horn 77.

Since polarisation reflected from the second reflector 76 varies between zero and 360 degrees in a complete circle in the azimuth plane, there will be two beams 70a and 70b

which will emerge from the apparatus. That is two beams 70a and 70b with a polarisation state at variance by 180 degrees which is the same as two beams 70a and 70b of the same polarisation but 180 degrees out of phase. Both beams 70a and 70b pass through the polariser 76 as each has an electric field perpendicular to the wires forming the polariser 76.

If the ferrite device 71 is energised longitudinally by the coil 72 or coils 72a and 72b the polarisation state of the beam 70 emerging from the ferrite device 71 will alter, that is the direction of the field in the beam 70 in this case it will rotate about the axis 78. Since the vertical polarisation direction of the reflected beam in the azimuth plane coincides with the direction of the field in the beam 70, the azimuth direction of the emergent beam from the reflector 76 will be changed accordingly.

In a modification of the arrangement described with reference to Figures 5 to 8, Figures 9a and 9b illustrate that a directional response can be made by dividing the ferrite device 71 into a number of sectors which describe cells 82 wherein one or more cell 82 can be energised at any one time. The directional response can be improved by increasing the number of sectors and attaching pole pieces to the machine faces 83 of the ferrite device 71 shown in figure 9b.

As shown in Figure 10a and 10b, it should be noted that the ferrite material 73 shown in Figures 5 to 8 can also be divided up into a number of sectors using biasing coils 72 imbedded within the ferrite material 73 which are arranged to energise one or more sectors of the ferrite material to be magnetised. Furthermore, a second layer of biasing

coils, not shown, could be either arranged in a Helmholtzian paired arrangement with the biasing coils 72 to increase the magnetisation of the ferrite material 73 or arranged independently of the biasing coils 72 to enable the ferrite material 73 to be divided into smaller sectors for finer control of a directional response.

5 The arrangement illustrated in Figure 5 can be made more compact, for example for use in a mobile communication system, by arranging the polarisers 75 and 76 in a plane perpendicular to axis 78, as illustrated in Figure 11. It should be noted that in this arrangement the first and second polarisers 75 and 76 are perpendicular to the axis 78. 10 The same reference as those used in Figure 5 have been used to indicate similar integers. However, in this arrangement, reflections from the polarisers 75 and 76 may be picked up by the horn 77 therefore, an isolator, not shown, such as a fixed Faraday rotation device can be positioned between the first polariser 75 and the horn 77 or a waveguide isolator can be positioned behind the horn 77 to mitigate the effect of reflections from 15 polarisers 75 and 76. A focusing lens 84 is used to focus the beam 70 emitted by the horn 77 onto the ferrite device 71.

As can be seen in Figures 12 and 13, in which the same reference as those used in Figures 5 and 11 have been used to indicate similar integers, a quarter wave plate 85 can be 20 positioned between the second polariser 76 and the reflector 81 so as to allow the communication system to both transmit and receive a circularly polarised beam 70. It should be noted that a fixed 45° quasi-optical rotator, not shown, may be required between the second polariser 76 and the quarter wave plate 85 depending on the sense of received circular polarised beam 70.

As shown in Figure 13, an alternative to the communication system illustrated in Figure 12 is to incline the second polariser 76 at substantially  $45^\circ$  to the axis 78 such that a received beam can be received in direction orthogonal to the axis 78. That is a receiving horn 87 is arranged in a position orthogonal to axis 78 and the received beam 70 is reflected by the second polariser 76 to be received by the receiving horn 87. It should be noted that a suitably arranged absorbing material 80 is used to absorb the beam 70 when it passes through an unenergised ferrite device 71 and is reflected by the second polariser 76.

This arrangement also lends itself to the inclusion of a birefringence phase plate 86 in front of the receiving horn 87 so that the direction of the incoming received beam 70 can be determined. Accordingly, once the direction of the received beam has been determined, the ferrite device 71 can be suitably energised to make a directional response to the transmitter that originally transmitted the received beam 70.

It will be understood that the physics of the embodiments may also lend themselves to embodiments with electro-optical components.